Standard Model and Supersymmetric Higgs at CDF

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on behalf of CDF collaboration

Outline:

Current Knowledge of Higgs

CDF searches :

- Direct Higgs (1 analysis)
- Associative Higgs (3)
- MSSM Higgs (2)

Tevatron Discovery potential

What we know about Higgs

- Higgs mechanism gives mass to Standard Model particles
- But required Higgs boson not yet discovered !
  - Therefore, some alternatives to experimentally check :

"Standard Model" (SM)

- Simplest Higgs mechanism possible
- Higgs is 1 particle
  - H
  - spin 0
  - electrically neutral
  - interacts with all SM particles
    - more strongly with higher mass particles

SM not wrong yet !

"Minimally Supersymmetric Model" (MSSM)

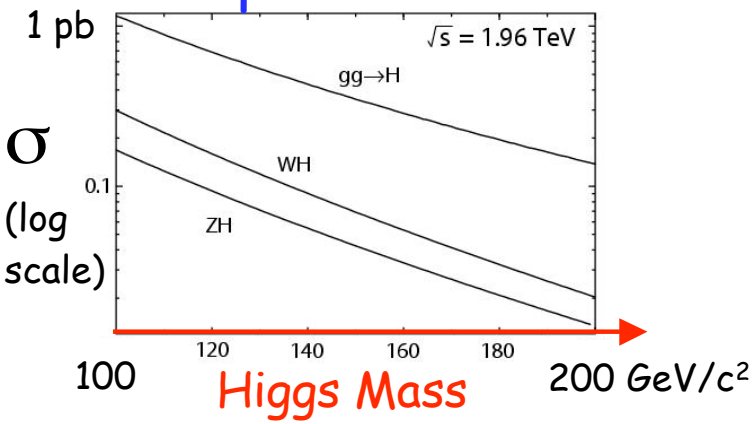
- Next most simplest Higgs mechanism possible
- Higgs are 5 particles
  - h, A, H, H+, H-
  - spin 0
  - electrically : -1,0, +1
  - interact with all SM particles
    - more strongly with higher mass particles
    - enhancement to down-type quarks from tan β parameter (relates to Vacuum Expec. Val.)

MSSM popular step toward unified theory

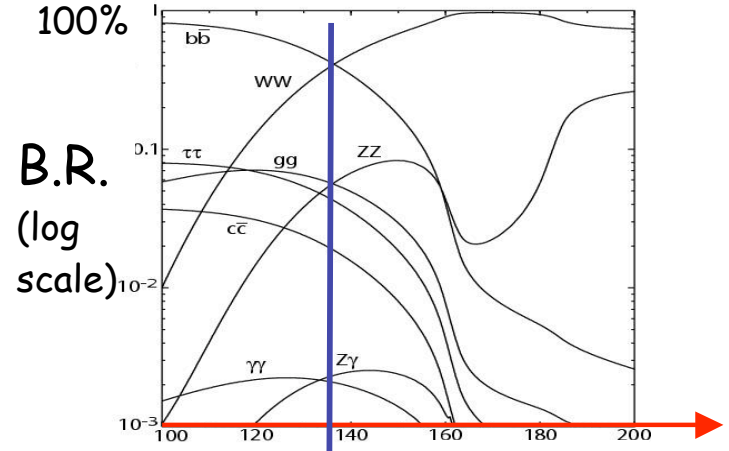
Higgs Production and Decay

($p\bar{p}$ collisions)

SM production



SM decay



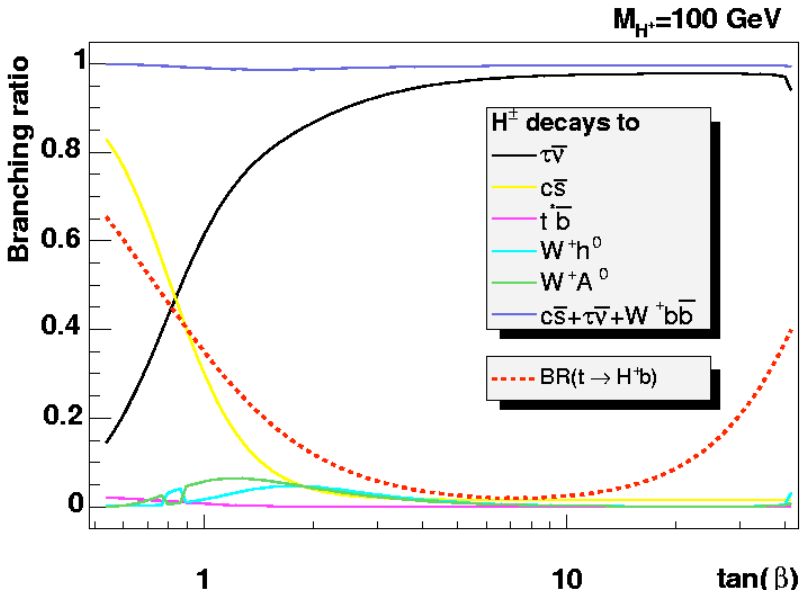
$H \rightarrow b\bar{b}$ at low M_H

$H \rightarrow \tau^+ \tau^-$ smaller

$H \rightarrow W^+ W^-$ dominates $M_H > 135$ GeV

SUSY production and decay

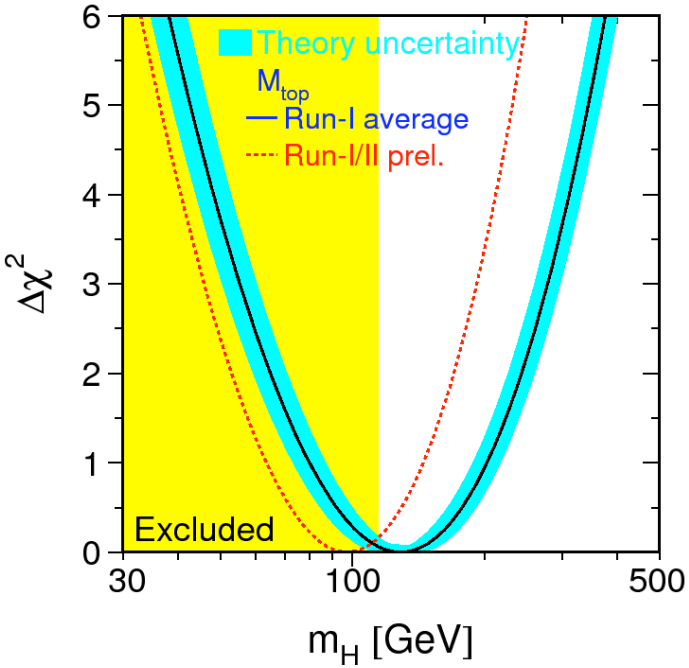
- 105 unknown parameters make this tough
  - tan β parameter most important at Tevatron
  - high tan β means Higgses (+1, 0, 1) couple to τ



Example: H^+ branching ratios for $m_H > m_t$

Expected Higgs mass (& type=SM or MSSM)

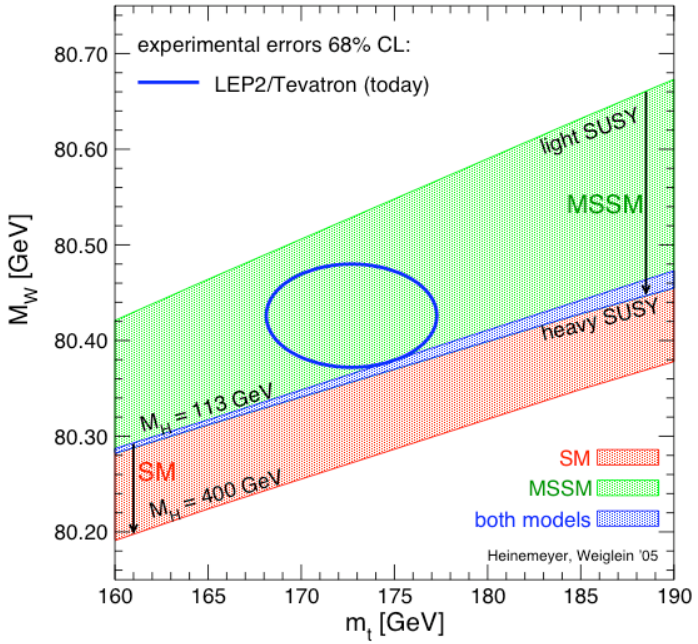
SM: From electroweak fits with new CDF/D0 Run I/II top mass 172.7 + 2.9 GeV/c^2



$$M_H = 91^{+45}_{-32}\ \mathrm{GeV}/c^2$$

$$M_H < 186\ \mathrm{GeV}/c^2\ @\ 95\%\ \mathrm{C.L.}$$

MSSM: top mass, W mass makes MSSM favorable



Search for SM pp → W* → WH→lνbb

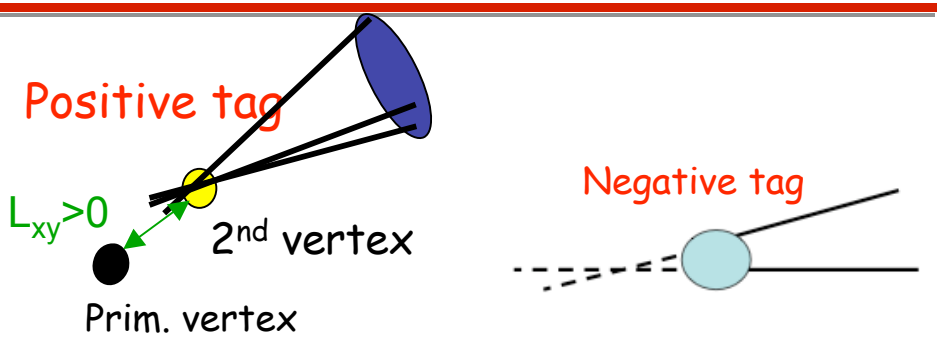
- Strategy :

  high P_T lepton + missing energy + 2 jets

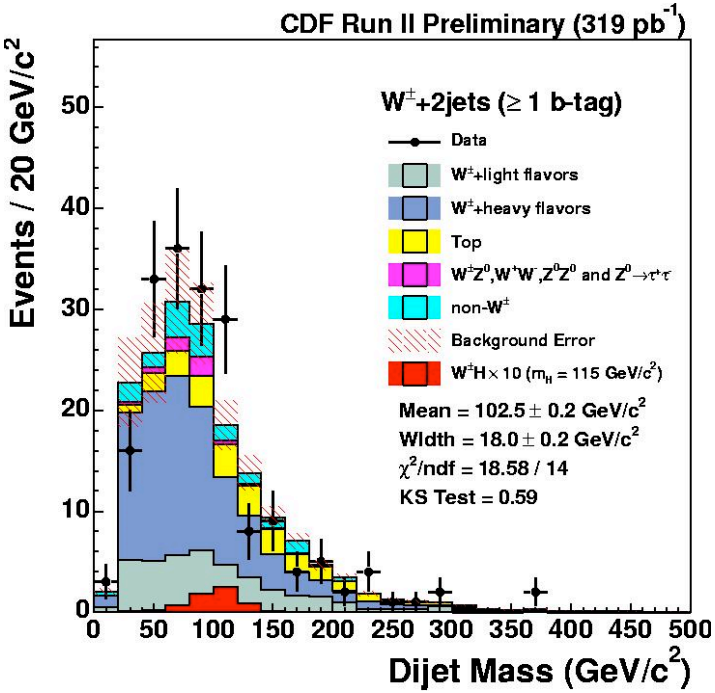
  ➢ Separate signal from W+heavy flavor and W+light flavor backgrounds

  ➢ Use b-tagging algorithm

  ➢ Requires MC estimations and excellent knowledge of "mistag" rate of light flavor jets



W+light flavor estimated from number of tags with negative lifetime



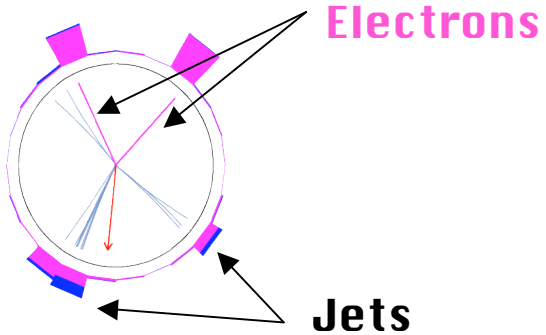
Results :

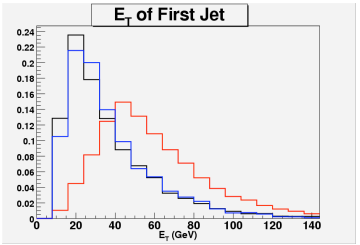
- Examine dijet mass for resonance
- Consistent with SM
- Set a limit on Higgs production :

  $\sigma(M_H = 115\ \text{GeV}) < 8.6$ pb

Search for SM $pp \rightarrow Z^* \rightarrow ZH \rightarrow l^+l^-bb$

- Strategy :
  - Identify Z boson decaying to two high Pt leptons + 2 or 3 jets (w/ b-tag)
  - Lepton ID cuts into acceptance
  - Use Artificial Neural Net (NN) to separate signal with main bkg of Z+jets





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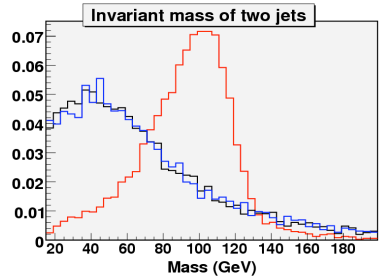

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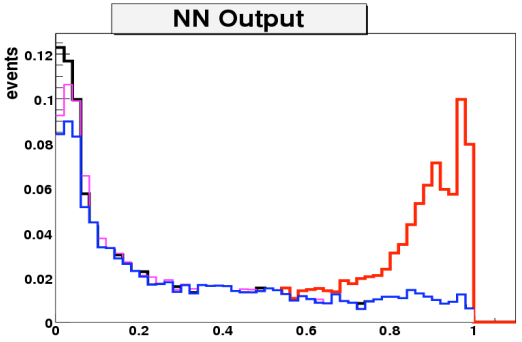


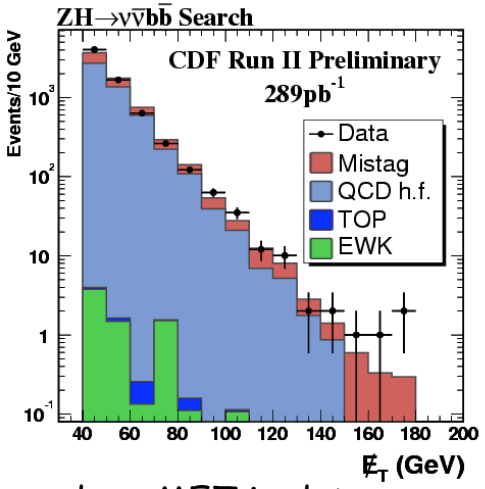
ZH
Zbb
Z+2partons

Results :

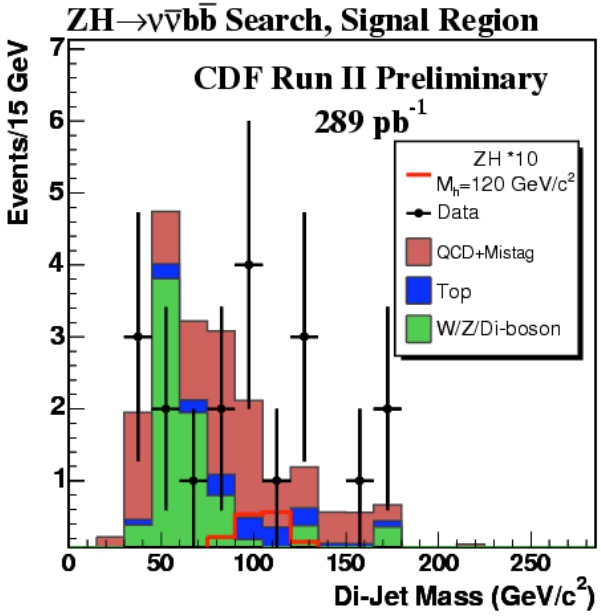
- NN improves S/B resulting in effective 1.6 increase in luminosity
- Expect result with 1 fb^{-1} data

Search for SM pp → Z* → ZH→νν̄bb̄

- Strategy :
  - Z decays to neutrinos
  - Search for large missing transverse energy (MET > 70 GeV) with 2 jets, 1 b-tag
  - Need to model MET well
  - Remove events where MET aligns with jet (mismeasured QCD dijet)



Scale MC to reproduce MET in data

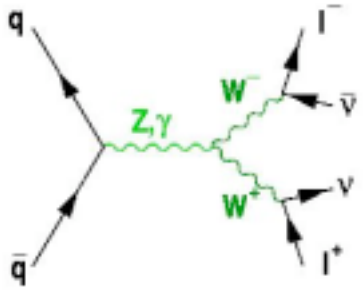


Results :

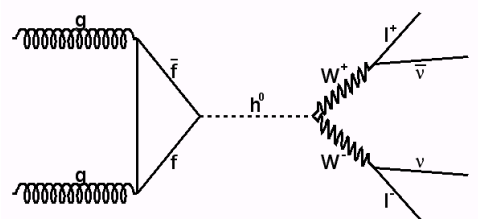
- Consistent with SM
  - Set a limit on Higgs production
  - σ (M_H=115 GeV) < 5 pb

Search for SM $pp \to H \to W^+W^- \to l^+l^-\nu\nu$

- Strategy :
  - Most sensitive channel to high mass Higgs
  - Search for 2 high P_T leptons and MET
  - Angular correlations between leptons different than WW BKG since H is scalar



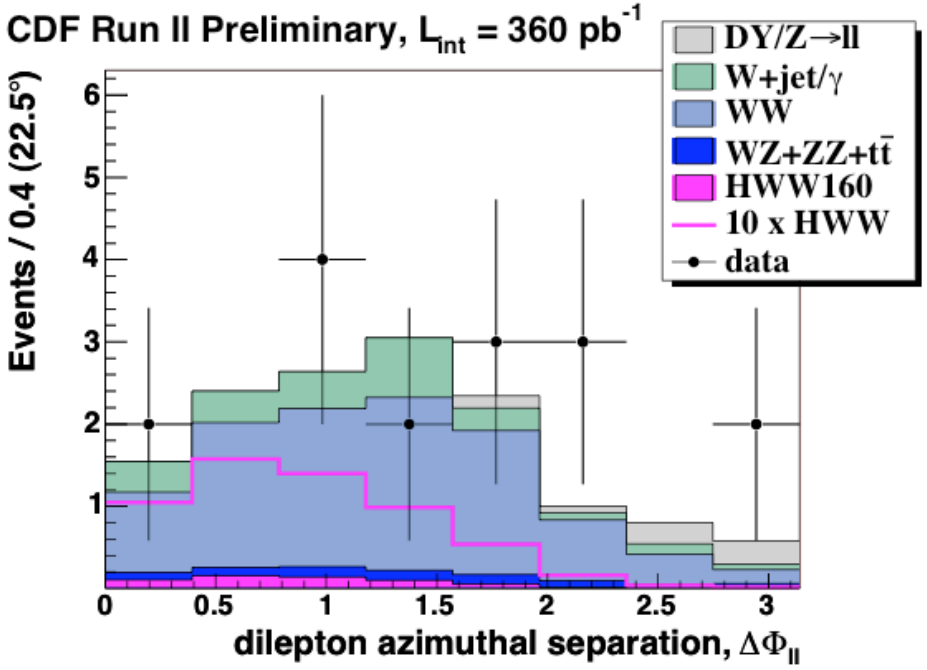
Background



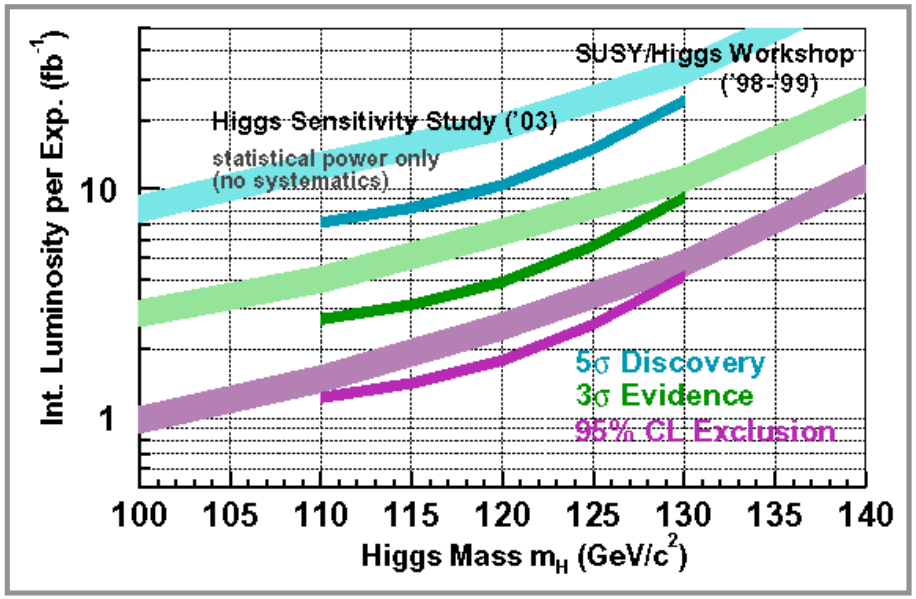
Signal

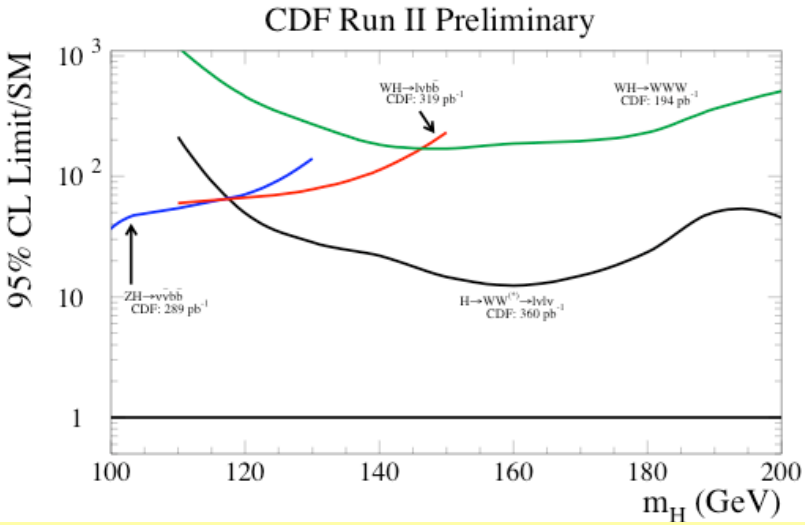
Results :

- Consistent with SM
  - 13.8 + 1.2 pred. bkg
  - 0.58 +- 0.04 pred. sig
  - 16 in data
  - σ (M_H=160 GeV) < 3.2 pb



Summary of SM Higgs searches





2003 Sensitivity Projections

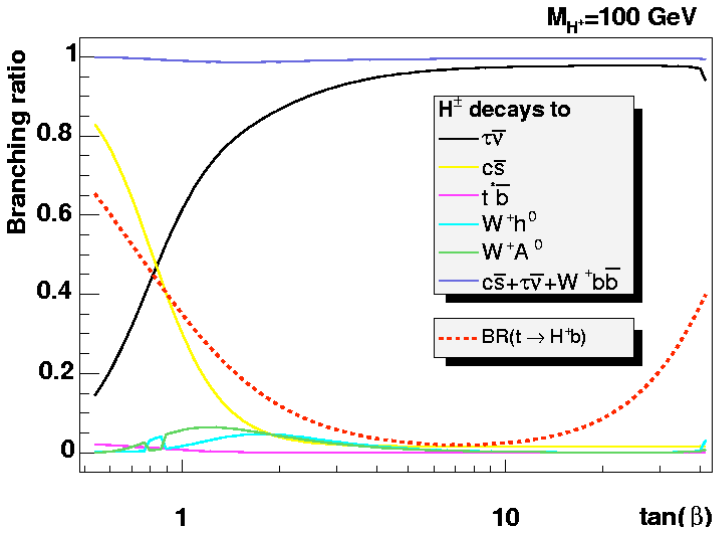
- m_H = 115 GeV
  - ~ 2 fb^{-1} for exclusion (if not there)
  - ~ **4 fb^{-1}** for m_H = 115 3σ evidence
- Assumes :
  - all Higgs channels combined at both CDF and D0
  - realistic data, no systematics
- 8 fb^{-1} by 2009 is design

2005 Status

- CDF, D0 preliminary results with 200 - 400 pb^{-1} data
  - channels not combined, some missing
  - need factor of 30-40
    - factor of ~20 from data up to 2009
    - factor of 2 from CDF/D0 combination
- Working on ways to improve sensitivity
  - Neural Nets for everyone ! (factor of ~1.7)
  - Improved jet resolution (1.1 for each 1%)
  - Improved lepton acceptance (> 1.5)

Search for MSSM $t \to H^+ b$

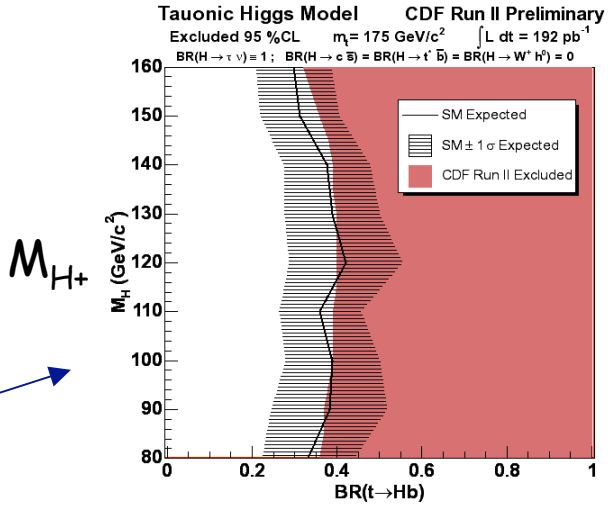
- Strategy :
  - In SM
    - $t \to W^+ b$
    - $W^+ \to l^+ \nu$ (1/3), $W^+ \to qq$ (2/3)
  - In MSSM (for $M_H < M_t$)
    - $t \to H^+ b$, $t \to W^+ b$
    - At high tan β, $H^+ \to \tau\nu$
    - At low tan β $H^+ \to c\bar{s}$
  - Find excesses and deficits w.r.t. SM top !



Results :

- No significant excesses or deficits found
- We can exclude regions of the M_{H+} vs tan β plane for various MSSM scenarios
  - Branching ratio limit independent of MSSM scenarios

BR(t→H⁺b)<0.4 @95%CL for **80 GeV<mH±<160 GeV**



M_{H+}

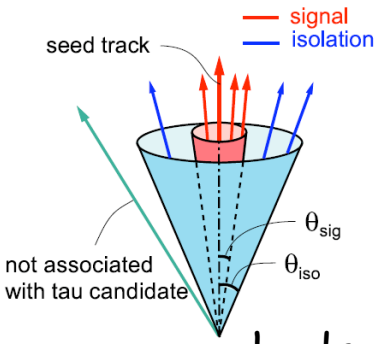
BR(t→H⁺b)

Search for MSSM $A/h \rightarrow \tau^+\tau^-$

- Strategy:
  - direct production cross-section (high)
  - high tan β enhances production of A
  - more stable to radiative corrections than A →bb
  - identify events with two taus

    one leptonic: $\tau \rightarrow e\nu / \mu\nu$

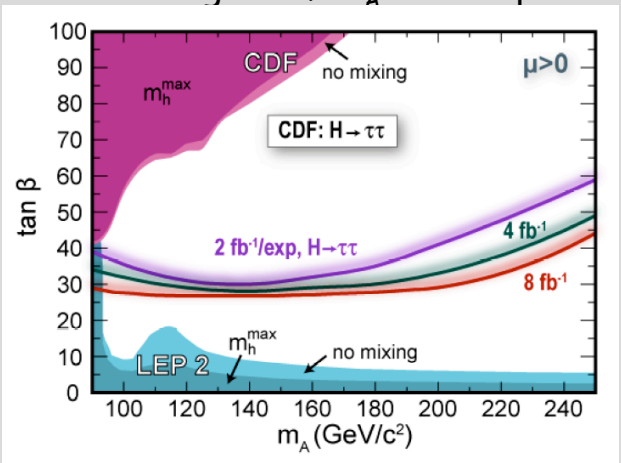
    one hadronic: "narrow" jet
  - Cut on sum of transverse (from $e/\mu + \tau_h$) and missing (ν) energy

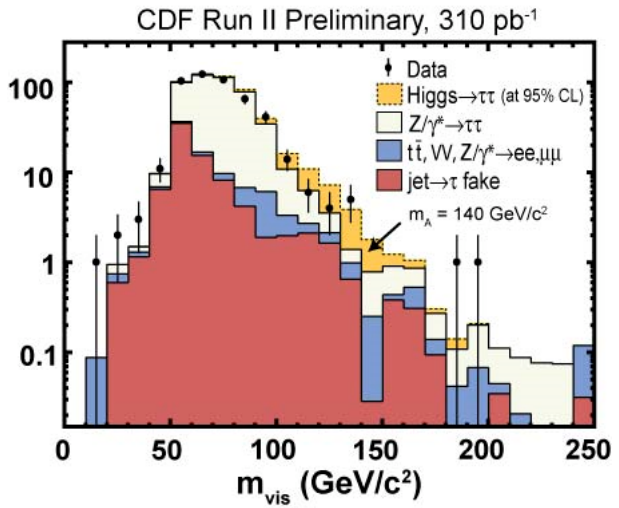


hadronic tau

Results:

- consistent with SM
- exclusion in region of m_A vs. tan β





Visible + missing transverse mass

Conclusions

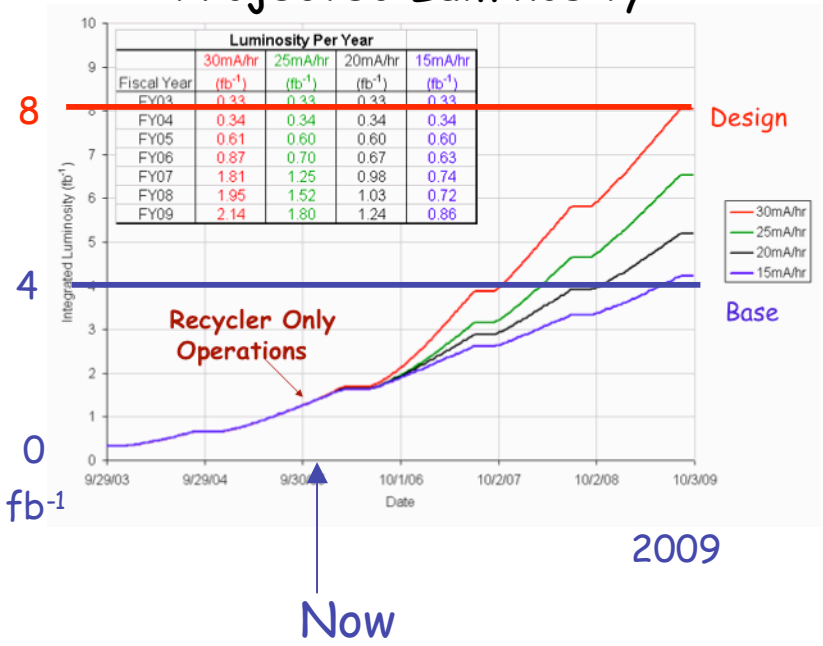
- CDF exploring all SM and MSSM Higgs possibilities
- SM
  - Direct Higgs production
    - high production cross-section
    - $H \rightarrow WW$
  - Associative higgs production
    - leptons + b jets (+ miss. E.) distinct signature
    - $WH \rightarrow l\nu$, $ZH \rightarrow \nu\nu bb$, $ZH \rightarrow l^+l^- bb$

  Limits will improve with luminosity and smarts !

  4 - 8 fb^{-1} can find us a light Higgs
- MSSM
  - Neutral Higgs
    - production cross section enhanced $(\tan \beta)^2$
    - $A \rightarrow \tau^+ \tau^-$
  - Charged Higgs
    - capitalize on knowledge of top
    - $t \rightarrow H^+ b$

  Cutting into allowed MSSM parameter space !

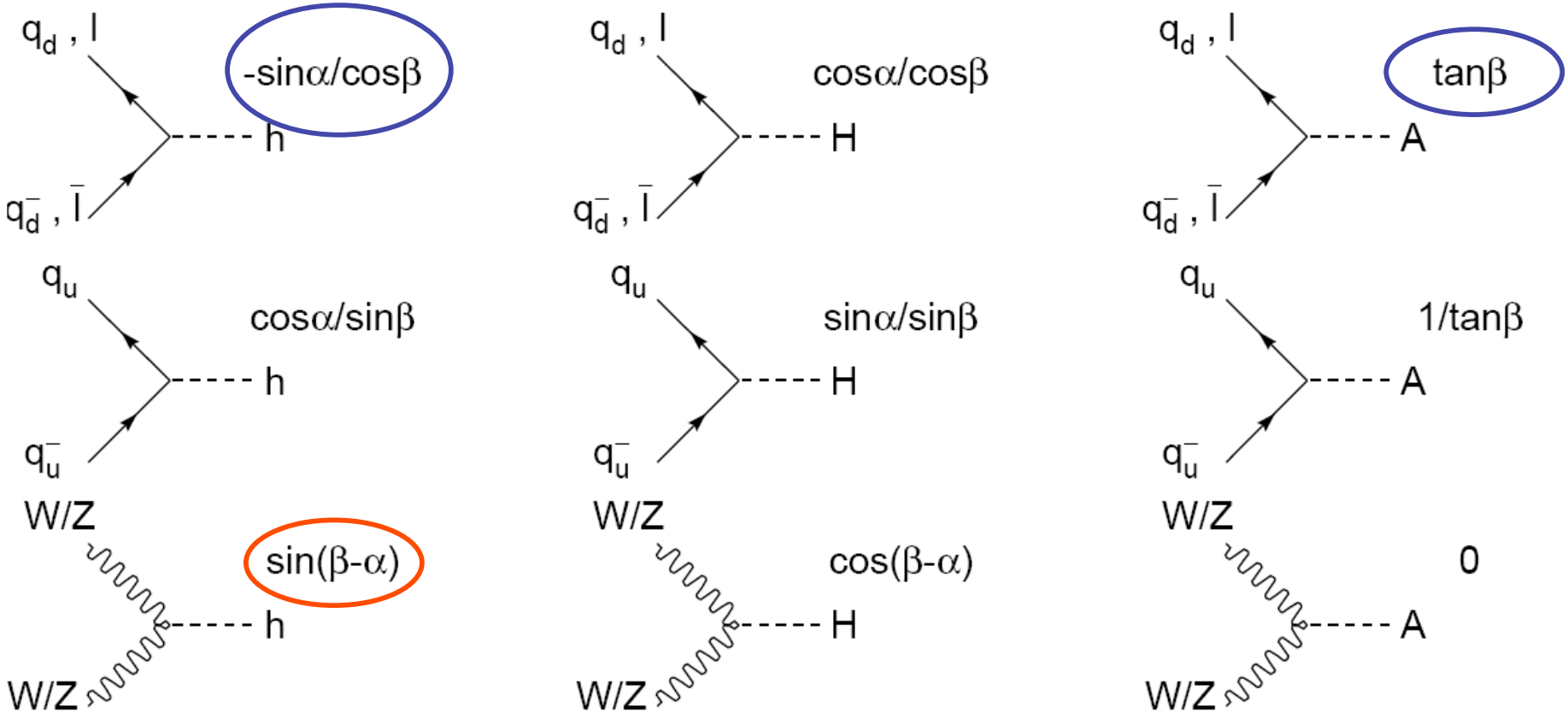
Projected Luminosity



Accelerator Division, CDF, and D0 working together against the clock

BACKUPS

Couplings of MSSM Higgs Bosons Relative to SM



W and Z couplings to H, h are **suppressed** relative to SM (but the sum of squares of h^0, H^0 couplings are the SM coupling). Yukawa couplings (scalar-fermion) **can be enhanced**

So How Do We Get There??

Start with existing channels, add in ideas with latest knowledge of how well they work.

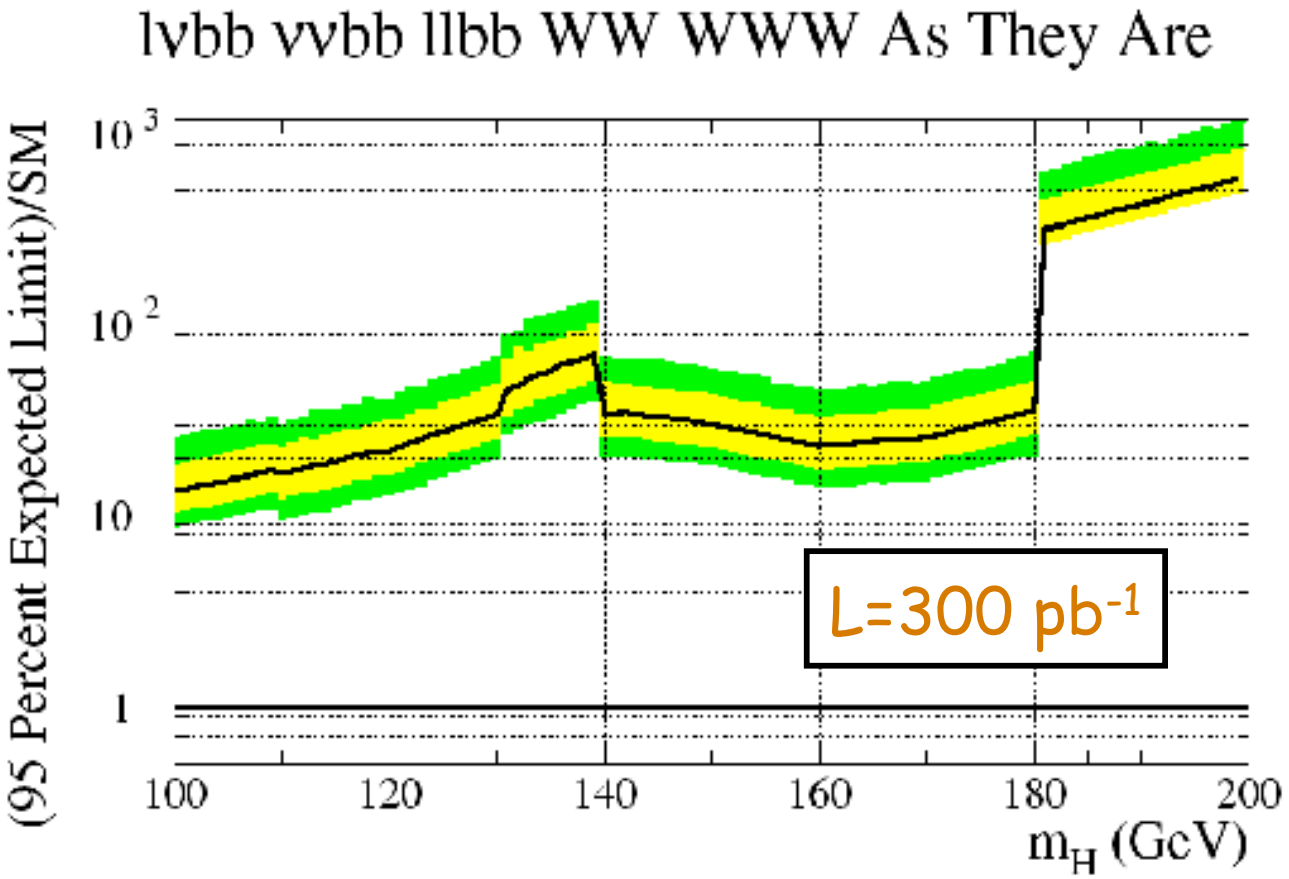
Luminosity Equivalent $(s/\sqrt{b})^2$

Improvement	WH→lνbb	ZH→ννbb	ZH→llbb
Mass resolution	1.7	1.7	1.7
Continuous b-tag (NN)	1.5	1.5	1.5
Forward b-tag	1.1	1.1	1.1
Forward leptons	1.3	1.0	1.6
Track-only leptons	1.4	1.0	1.6
NN Selection	1.75	1.75	1.0
WH signal in ZH	1.0	2.7	1.0
Product of above	8.9	13.3	7.2
CDF+DØ combination	2.0	2.0	2.0
All combined	17.8	26.6	14.4

Expect a factor of ~10 luminosity improvement per channel, and a factor of 2 from CDF+DØ Combination

Sensitivity with Existing CDF Analyses

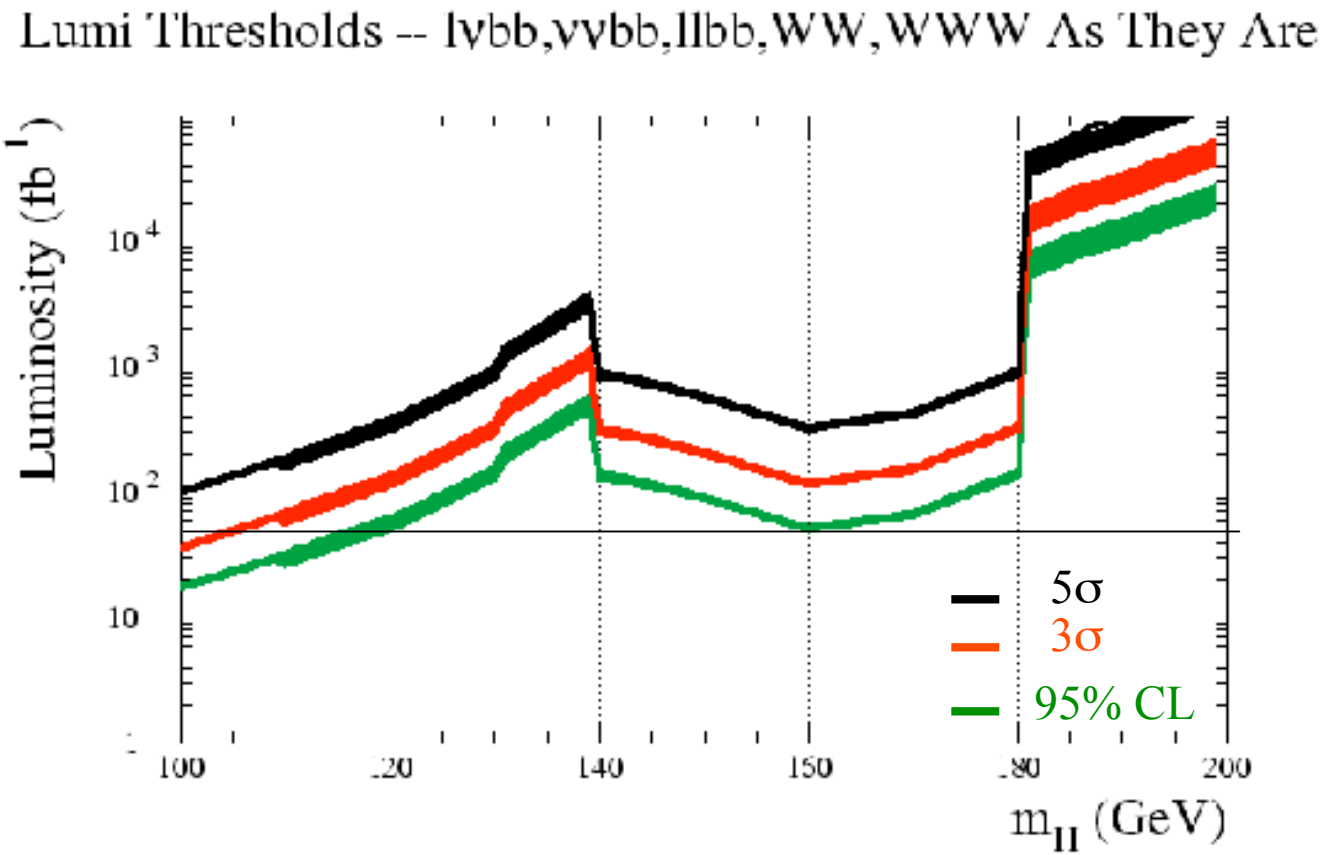
Cross-Section times branching fraction limit as a multple of the SM rate



Luminosity Thresholds for CDF's Channels Combined

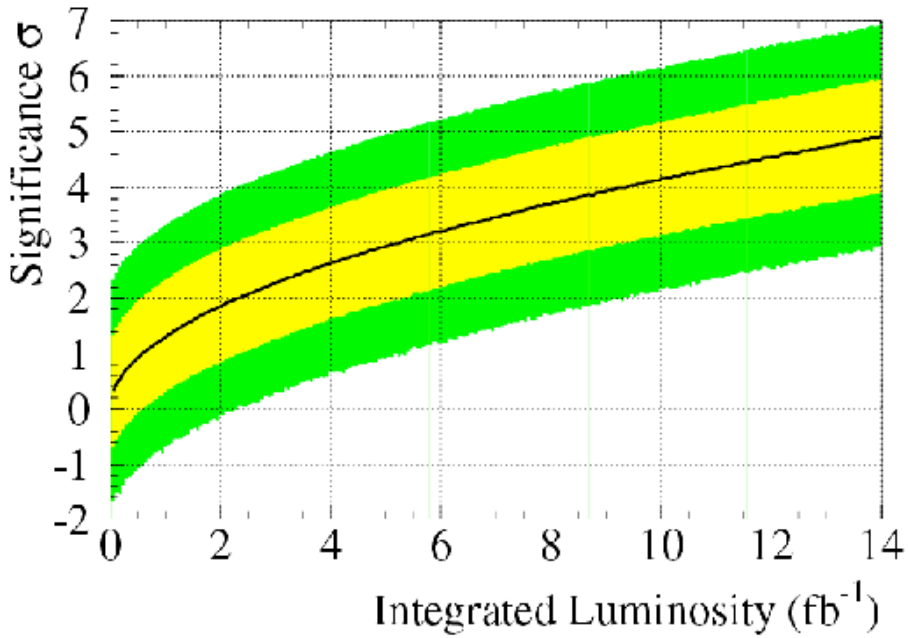
Assumption: Systematic errors scale with $1/\sqrt{\int \mathcal{L} dt}$

All channel's luminosities scaled to 300 pb^{-1} and then scaled together



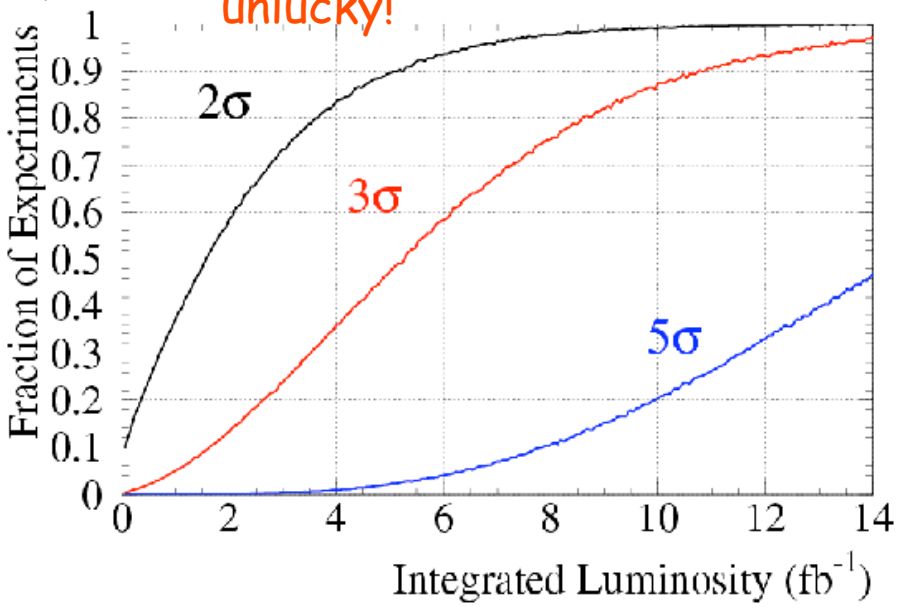
Width of bands given by systematic errors on/off

Expected Signal Significance CDF+DØ vs Luminosity



per experiment

It's possible to be lucky or unlucky!



per experiment

m_H=115 GeV assumed

CDF sees Z→bb decays in Run 2

Double b-tagged events with no extra jets and a back-to-back topology are the signal-enriched sample: $E_t^3<10$ GeV, $\Delta\Phi_{12}>3$

Among 85,784 selected events CDF finds 3400±500 Z→bb decays

- signal size ok
- resolution as expected
- jet energy scale ok!

This is a proof that we are in business with small S/N jet resonances!

CDF expects to stringently constrain the b-jet energy scale with this dataset